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Challenges in cost analysis of innovative maintenance of distributed high-value assets

L. Kirkwood[a]*, E. Shehab[a], P. Baguley[a], P. Amorim-Melo[a], I. Durazo-Cardenas[a]

[a]Department of Manufacturing, Materials and Design, Cranfield University, Cranfield, UK

* Corresponding author. *E-mail address:* l.kirkwood@cranfield.ac.uk

Abstract

Condition monitoring is an increasingly important activity, but there is often little thought given to how a condition monitoring approach is going to impact the cost of operating a system. This paper seeks to detail the challenges facing such an analysis and outline the likely steps such an analysis will have to take to more completely understand the problem and provide suitable cost analysis. Adding sensors might be a relatively simple task, but those sensors come with associated cost; not only of the sensor, but of the utilities required to power them, the data gathering and processing and the eventual storage of that data for regulatory or other reasons. By adding condition monitoring sensors as a sub-system to the general system an organisation is required to perform maintenance to the new sensors sub-system. Despite these difficulties it is anticipated that for many high value assets applying condition monitoring will enable significant cost savings through elimination of maintenance activities on assets that do not need such cost and effort expended on them. Further savings should be possible through optimisation of maintenance schedules to have essential work completed at more cost efficient times.

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Keywords: Cost engineering; maintenance; condition monitoring; cost optimisation; data cost

1. Introduction

The practice of applying sensor technology to accurately determine how well a hardware asset is performing is of growing importance. The damage done to an organisation through the downtime caused by unplanned maintenance and the resulting loss of reputation is a problem that many industry and government organisations are seeking to address through improvement of condition monitoring and the expected improved reliability that will result. Furthermore, the condition monitoring approach will likely be a driver for reducing cost as un-needed but previously scheduled maintenance is avoided.

Within the EPSRC funded AUTONOM: integrated through-life support for high-value systems project at Cranfield University there is an interest in the condition monitoring of many high-value assets across a range of industries [1]. The approach is not just focused on condition monitoring but gathering data from multiple sources and performing a data-fusion type analysis to provide enough information to perform some automated scheduling and apply cost-engineering methodology to reach cost effective solutions. In particular this research project seeks to highlight and address the

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maintenance challenges facing each of the project partners

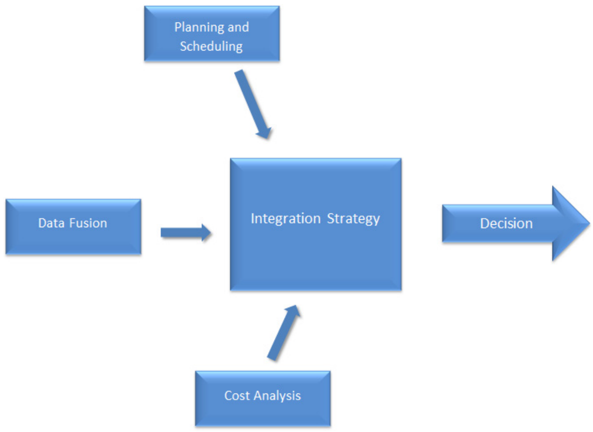

Figure 1: Structure of decision making approach

and provide cost estimates of various maintenance schedule options. Parametric cost estimation methods use identified drivers of cost to formulate a cost estimation relationship and make cost predictions of cost based on that relationship. The parametric cost estimation method is preferable in situations when data is limited and estimates need to be swiftly generated. Using the combined information from Data mining, schedule and cost information asset managers can be supported in making decisions. It is expected that by optimising maintenance schedules each of the partner organisations can make significant savings to their maintenance budgets, without increasing risk.

Figure 1 demonstrates the combined approach to decision making, by using data-fusion, scheduling and cost analysis within an integrated framework.
To validate the projects findings, it is likely that a case-study will be completed by modelling one of the significant challenges facing Network Rail. It is anticipated that by providing a solution to their very large scale issues a solution will be found that can be applied to the other partners. Network Rail are keen to radically improve the condition monitoring process across a dispersed and high value asset, namely the entire rail network. Currently the rail infrastructure in Britain is maintained and managed by Network Rail while different regions of the UK have private companies operating the train service within their franchised regions. One of the obvious research gaps is to analyse which locations on the network are suitable for detailed condition monitoring based approaches to maintenance and which are likely to be more cost effectively served by current condition monitoring approaches (often sending engineers for inspections).

A planned maintenance approach typically results in some unnecessary maintenance work being done on an asset. While exact figures are not available, it is inevitable that some of the current ~2billion GBP maintenance budget [2] within Network Rail is being spent on repairing assets that do not require maintenance work. Unplanned maintenance due to unforeseen failures are estimated to cost 120million GBP per year [3]. Such unforeseen failures should be dramatically reduced by using condition monitoring and therefore a further saving is attributable to condition monitoring. Potential savings from this project are therefore likely to be significant.

2. Related Research

A few authors have approached the issue of maintenance costs for railways. These typically have a focus on a particular problem, such as the work of Reddy et al [4] that focuses on wear of the rail and the economic cost of reducing that wear through a lubrication scheme. A similar single issue analysis is the work by Andrews [5] which examines tamping of the track to correct gauge issues and developed models that use a Petri Net approach to plan the flow.

A very relevant example of cost engineering within the Rail industry is that of Ling et al. [6], which created a cost model and validated using a switch and crossing case study. The developed COMpairCOST model required detailed input from a switch and crossing expert to perform so accurately, however there are a great many different maintenance activities that need to be done to address the many different possible faults. The work of Cannon et al. [7] provides a very clear analysis of many of the faults that can occur to rails within the railway industry. Many of the faults described by Cannon et al. [7] were later examined by Patra et al. [8] which developed some cost estimating equations for the associated maintenance work required to correct those faults. It is worth considering that though the equations of Patra et al. [8] or the detailed expert driven model from Ling et al. [6] might suit a bottom-up cost-estimating approach but when we consider the scale of the problems facing Network Rail at the strategic level a detailed approach might require an unfeasible level of detail. Furthermore, when the multiple project partners and industries are considered such a detail driven approach becomes clearly infeasible.

A more strategic analysis of rail infrastructure costs modelled the total cost of existing activities [9]. It is worth noting that the rail network studied is rather limited in scale (930Km), but this demonstrates that a top-down approach to modelling cost of maintenance can be applied to rail issues. The only maintenance approaches used in this study are corrective maintenance and preventative maintenance; condition based monitoring is not used. It is anticipated that condition monitoring would be adding to the cost in some regards but applying downward pressure on the overall cost estimate. To the authors knowledge, no literature has so far been produced that compares the cost of deploying different fault detection methodologies to the infrastructure managed and maintained by Network Rail.

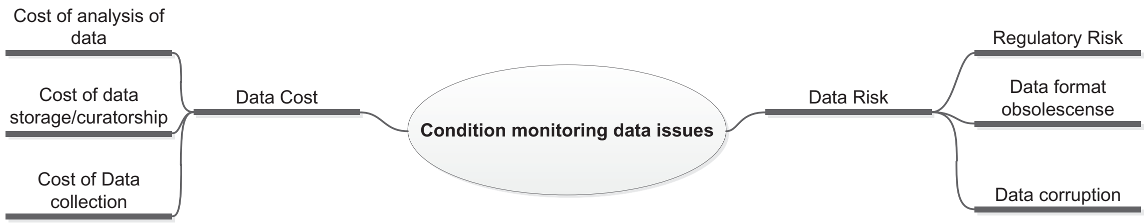

Figure 2: Cost/Risk of Condition monitoring data

3. Challenges

A maintenance cost model will be developed for this work. Inputs to the model will include maintenance fault type, from the condition-monitoring the model should have an indication if the maintenance work is urgent or can be safely catalogued for later inspection. If the work can be safely delayed it allows for an optimisation process to seek a most cost effective solution. The cost optimisation process will require a method to predict maintenance cost, which is likely to be based on parametric cost estimation methods. Typically parametrics are used during very early stages of projects where specific details are lacking but a more general view is sufficient.

For a parametric cost analysis, effort will have to be put towards identifying potential cost drivers and later on, testing them for relevance to the final cost. So far a number of potential cost drivers have already been identified as relevant to condition monitoring of rail infrastructure. Such as:

- Cost of condition monitoring equipment (sensors, utilities to power the sensors, any monitoring of the sensor equipment)
- Costs associated with data (digital storage, processing, curatorship and security)
- Analysis of delays in the UK rail industry and the fines structure that is used between operators and Network Rail
- Analysis of the effect of planned versus unplanned maintenance
- Different fault types (i.e. Rail cracking fault compared to a points failure)
- Geographical factors (location of fault, effect of weather, etc)
- Scheduling related issues (seasonal variations in cost, time-of-day variation in cost)

Many relevant facts are individually available within the literature as many of the sub-challenges facing this project have been looked at. For example the project is planning to deploy data mining techniques which should be subjected to cost analysis. Research performed to develop the data-mining cost model (DMCoMo) identified twenty-three possible cost drivers for data-mining projects [10] but managed to reduce the model to the eight cost-drivers with highest impact and significance. The DMCoMo model will inform how to calculate part of data costs for my own work. Therefore, the eight identified cost drivers for data-mining projects will likely be used as sub-drivers of the over-all data cost driver.

While there is likely a cost contribution associated with data storage, there may also be risk issues (see figure 2). Condition monitoring increases the data gathered and in many organisations or industries there will be a regulatory requirement to store that data. Even if there is no regulatory requirement it may well be advantageous to have data relevant to maintenance available for experts within the organisation. Recent work on risk of digital storage [11] clearly showed that digital storage is very vulnerable to faults when file-compression schemes are being used. Data format obsolescence is another potential risk for long-term data storage. In the rail, or nuclear industries the asset lifetime is very long. Civil engineering assets like bridges in the rail industry have an average age in excess of 100 years and the legacy from nuclear is going to be even longer lasting. If condition monitoring data is gathered and stored and deemed useful to future decision making or regulatory purposes then clearly for highly regulated industries the life-time cost modelling efforts also need to consider risk to assets both physical and digital. For many organisations an analysis needs to be performed that assesses if there is a need to accept higher digital storage costs through storing uncompressed files or if by compressing data and getting costs minimised a higher risk of data errors can be tolerated.

The data example neatly focuses the mind on risk and illustrates that different business sectors might have very different attitudes about risk to their assets. While in the rail or nuclear industry cost becomes a less important factor compared to minimising risk of accidents. Within other industries risking an engineering asset might be very sensible considering the high costs of project delays. Analysis of risk is likely to be important when optimising schedule.

It is entirely possible that for many organisations assets a condition monitoring based approach is unlikely to be appropriate and it is likely that the project will collect much of the relevant data to answer that question. A fairly simple process should make much clearer the case for deploying condition monitoring:

- Attempt to accurately determine the cost of condition monitoring
- Establish cost of current fault detection methods
- Determine how cost-effective condition monitoring will be for a range of situations

The model described at the start of this section should be ideal for addressing the third point. By using a parametrics based approach the model should be suitable for re-purposing to new industries. There is evidence that at least some of the common rail problems follow predictable progressions, with references 4,5,7,8 all reporting some predictive relationship for asset condition. Prediction of remaining life during condition monitoring is a field with its own literature, exploring various methods (for example [12&13]). When to perform maintenance on a system is therefore not as trivial a problem as it may seem. In safety conscious industries many assets that are still safe to use are shut-down for maintenance activities, incurring not just the maintenance cost but also a denial of service and possible reputational cost. Determining how cost effective condition monitoring will be for an industry is a complex problem. Definitive answers will be difficult to achieve therefore both sides of this equation will likely be estimates. However it is likely that many industries do not require an exact calculation but rather an indication of the break-even point and probability that the break-even point has been passed, as this can support the decision to invest in condition monitoring activities.

4. Conclusions

There appears to be limited amounts of literature on the cost prediction of maintenance activities. To the authors knowledge, there is no literature available that links the effect of applying condition monitoring to the cost of maintenance. This area will clearly be of increasing interest as excellence in maintenance is sought by organisations seeking to reduce the life-cycle costs of products, particularly high-value assets.

Future research is likely to be constrained by a lack of detailed information available, which will likely require developing of a parametric based method using multiple cost-drivers to predict maintenance costs and optimise maintenance schedules. The parametric cost estimation approach will result in a model that has higher uncertainty but is likely to be suitable for a range of asset types across a range of industries. Each industries approach to risk of the relevant asset will have to be considered when optimising maintenance schedules of the relevant assets.

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